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Beech Utilization Series No. 5

Gluing Techniques For Beech

by

W. Z. Olson and R. F. Blomquist

Northeastern Technical Committee
On the Utilization Of Beech

in cooperation with

Northeastern Forest Experiment Station
Forest Service, U.S. Dept. of Agriculture

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FOREWORD

The wood of the American beech tree (Fagus grandifolia Ehrh.) is well suited for a large number of uses, and it is rather widely used by manufacturers. Yet the amount used is not in proportion to the amount that grows in our northeastern forests. The utilization of beech--both in the woods and in the factory--has been recognized as a problem.

One reason for this is in the nature of the wood: it has a reputation for being difficult to season. Another is that many of the beech trees in our forests are of poor quality. And there are some plain prejudices against beech.

Research is finding ways to utilize beech as efficiently as any of the other comparable hardwoods can be handled. Considerable information about beech has been gathered. Yet most of this information is available only in fragmentary form in scattered technical reports. Some of it has never been published.

To study the problems of putting beech to the uses it deserves, and to promote the better management of the forests in which it grows, a Northeastern Technical Committee on the Utilization of Beech was organized in 1949. This committee, which includes representatives of Federal and State forestry agencies, universities, and state experiment stations, decided to assemble and publish the available information about the utilization of American beech.

As its part of this cooperative project, the Northeastern Forest Experiment Station has undertaken to edit, publish, and distribute the series of reports that will contain this information.

The subjects of these reports will be as follows:

* Physical and mechanical properties of American beech.

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GLUING TECHNIQUES FOR BEECH

by

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INTRODUCTION

BEECH IS BEING USED in increasing amounts by the furniture industry, especially in areas where maple and birch are becoming less readily available. It is also probable that the use of beech veneer in plywood will increase where birch and other hardwoods are now used.

Laboratory tests and commercial experience have indicated that beech generally does not present any greater gluing problems than do birch, hard maple, hickory, and other species of generally high density. Because of the increasing interest in the use of beech, this report was prepared to recommend certain techniques that may be helpful to the fabricator in gluing beech.

[1] MAINTAINED AT MADISON, WIS., IN COOPERATION WITH THE UNIVERSITY OF WISCONSIN.

Gluing Conditions Considered

Research in the gluing of wood (8)[2] has established the general principle that the greater the density (or the specific gravity) of the wood, the more carefully the gluing conditions must be controlled to produce good joints. The following gluing conditions will be considered in this report:

Preparation of the wood.

Preparation of the glue.

Amount of glue applied.

Assembly time.

Temperature of glue and wood.

Pressure and pressure period.

Conditioning the assembly after gluing.

The best criterion of a good glue joint in wood is wood failure when the joint is broken; that is, the joint cannot be destroyed without destroying the wood. Since the high-density species generally have higher strengths than the low-density species, it follows that they will give greatest resistance to failure and thus highest joint strength in glue-line tests.

To obtain these high levels of strength requires careful control over the various factors in the gluing process. In gluing wood of low density, considerable variation may be allowed in one or more of the above conditions, and good joints may still result. But because beech is a very dense wood, all gluing conditions should be controlled within rather narrow limits to obtain satisfactory joints.

As is well known, wood undergoes dimensional changes when its moisture content changes. The amount of change in

[2] UNDERLINED NUMBERS IN PARENTHESES REFER TO LITERATURE CITED, PAGE 19.

dimension for each percent of change in moisture content depends on the species. Generally the high-density species swell and shrink more than the low-density species. Thus, high-density species such as beech will cause greater mechanical stresses on the glue line when subjected to moisture change than would low-density species. Satisfactory performance of beech products in service therefore requires the joints to be of highest possible quality.

Table 1.--Conditions[1] used in preparing beech plywood specimens, and results of shear tests

Type of glue	Closed-assembly time	Curing temperature	Period under pressure	Plywood shear-test results[2]				Delamination-test results[3]		
				Dry[4]	Wet[5]	After boiling cycle[6]	After soaking-drying cycle[7]	Panels tested	Panels passed[8]	Average delamination[9]
	Minutes	°F.	Hours					Number	Number	Inches
Starch	5	75	16-24	388-1	0-0	--	--	3	0	31.2
	15	75	16-24	354-1	0-0	--	--	2	0	30.4
Casein	5	75	16-24	373-3	77-0	--	--	3	0	13.6
	15	75	16-24	337-5	171-0	--	--	3	3	1.1
Urea-resin	5	75	16-24	398-19	247-5	--	--	3	3	1.1
	15	75	16-24	392-26	270-14	--	--	2	2	.9
			Minutes							
Soybean	5	75	30	252-1	0-0	--	--	3	0	23.3
	15	75	30	222-0	34-0	--	--	3	2	2.8
Urea-resin	5	250	6	562-88	569-71	--	--	3	3	.0
	30	250	6	534-85	557-86	--	--	2	2	.0
Urea-resin[10] (extended)	5	250	6	363-4	24-0	--	--	3	1	8.2
	30	250	6	354-3	165-0	--	--	3	3	.4
Phenol-resin	60	310	10	424-71	458-68	388-73	423-83	--	--	--
	24 hours	310	10	453-73	423-78	365-85	407-84	--	--	--

[1]Other conditions common to preparation of all specimens: Moisture content of veneers, 6 percent; pressure applied in gluing, 200 pounds per square inch; temperature of room during assembly periods, 75° F.

[2]The first value is the average shear strength in pounds per square inch; the second value is the average estimated wood failure in percent. Each value is the average for 25 specimens, except for the phenol-resin glue, for which results for 50 specimens were averaged.

[3]This test consists of soaking a 6- by 6-inch specimen for 4 hours in water at 70° to 100° F., drying in air at 70° to 100° F., and repeating this cycle. Delamination, any part of which reaches one-eighth inch in depth, is then measured along both glue lines at the edges of the panel.

[4]Tested dry at 6 percent moisture content.

[5]Tested wet after soaking for 48 hours in water at room temperature.

[6]Tested wet after immersion in boiling water for 4 hours, drying at 145° F., for 20 hours, immersion in boiling water for 4 hours, and cooling to room temperature in water.

[7]Tested wet after soaking for 48 hours in water at room temperature, followed by three cycles, each consisting of drying for 8 hours at 145° F. and then soaking for 16 hours in water at room temperature.

[8]Commercial Standard CS35-49 for hardwood plywood permits not more than 2 inches of continuous delamination. Those panels that met this requirement were considered to "pass."

[9]Average for both glue lines in all panels tested, regardless of continuity of delamination, but with the depth of delamination being one-eighth inch in at least one point.

[10]Extended 100 percent with wheat flour (based on dry weight of resin).

Table 2.--Conditions[1] used in preparing beech block-shear specimens, and results of shear tests

Type of glue	Closed-assembly time	Curing temperature	Average shear-test results[2]
	Minutes	°F.	
Animal	1/2, 5	70, 80	[3]2,925-72
Animal[4]	1/2	90	[3]1,950-16
Starch	5, 12	75	[3]2,840-53
Casein	5	75	2,850-38
	12	75	3,400-31
Urea resin	5	75	2,909-66
	12	75	3,356-78
Resorcinol resin	5	75	2,946-32
	30	75	3,028-46
	30	90	3,408-56

[1]Other conditions common to preparation of all specimens: Moisture content of wood, 6 to 7 percent; pressure applied in gluing, 200 pounds per square inch; pressure period, 16 to 24 hours.

[2]The first value is the average shear strength in pounds per square inch; the second value is the average estimated wood failure in percent. Each value is the average for at least 20 specimens from at least 4 different joints.

[3]Data from U. S. Dept. Agr., Dept. Bul. 1500 (8). The values shown are average for 1 or 2 assembly periods indicated.

[4]In this case, the glue was used under conditions that are known to be conducive to starved joints.

Information Available

Although some work has been done to develop acceptable gluing practices for beech, the range of conditions for gluing has not been thoroughly investigated. Many of the procedures advised in this report are based on generally accepted practices in gluing. Whenever possible, previous experience in gluing other species, particularly those most similar in density to beech, has provided the basis for recommending techniques. In addition, the results of actual tests involving beech have been considered.

Tables 1 and 2 include the results of tests made on glued beech joints at the Forest Products Laboratory. The specimens were tested in accordance with American Society for Testing Materials' methods D905 for the block-shear test (1) and D906 for the plywood shear test (2), and the tests described in Commercial Standard CS35-49 for hardwood plywood (9).

SELECTION OF PROPER TYPE OF GLUE

A number of different types of glue can be used for gluing beech. They are prepared from materials of natural origin or formulated from synthetic resins.

Nonresin glues include: (1) Animal or hide glue from hoofs, hides, sinews, or bones of cattle, sold ready to use for mixing with water and melting for use as a hot glue. (2) Vegetable or starch glues, usually prepared by the user by cooking specially processed starches, such as cassava starch, in water. (3) Casein glue, prepared from the protein of milk by addition of lime and caustic soda, available in powder form ready to mix with water. (4) Soybean glue, derived from soybean protein and not usually available in powder form. All these nonresin glues are pressed at room temperature.

Synthetic-resin glues include: (1) Urea-resin glues prepared by reacting urea and formaldehyde and formulated for either hot or cold pressing. Resins are available in liquid or in powder form to be mixed with water. Cereal flours are often added to reduce glue-line costs. (2) Phenol-resin glues prepared by reacting phenol and formaldehyde, and available in liquid, powder, or film form, normally for hot pressing. (3) Resorcinol-resin glues prepared by reacting resorcinol and formaldehyde, and usually supplied in liquid form for pressing at room temperature.

Generally, when properly used each type will produce joints of similar initial dry strength, and these joints should develop strength equal to that of the wood. The principal exception is soybean glues; in species of high density they generally produce weaker joints than the other glues.

The various types of glue differ, however, in durability of the glue line produced, in cost, and in conditions

required for use. The user must decide which type fits his requirements best.

For Products To Be Used Outdoors

Glued beech products that are to be exposed to weather or to receive marine use should be prepared with hot-press phenol-resin, hot-press melamine-resins, or room-temperature-setting resorcinol-resin glues.

For certain constructions of beech (where heavy mechanical stresses, due to swelling and shrinking, may be encountered), curing the resorcinol resins at somewhat elevated temperatures (up to 140° F.) may be desirable. When properly used, any of these glues should prove satisfactory under severe exposure conditions (13).

For Products To Be Used Indoors

Glued beech products that will not be exposed outdoors or to severe moisture conditions can be prepared with several types of glue. Some of these glues are more durable than others and will produce more durable joints in heavy or highly stressed constructions. All of these glues may be equally durable under the usual interior conditions, but they are listed in the order of their durability under more severe conditions:

1. Urea-resin, hot-pressed, unextended.
2. Urea-resin, room-temperature-setting, unextended.
3. Urea-resin, hot pressed, extended with cereal flours.
4. Urea-resin, room-temperature-setting, extended with cereal flours.
5. Casein.
6. Soybean.
7. Animal and starch.

The above listing is based principally on the moisture resistance of the glues as shown by the delamination-test results in table 1. It is confirmed by various other tests for the durability of these various glues (4, 13). Any glue suitable for products to be used outdoors could, of course, be used in products for interior use.

RECOMMENDED

GLUING CONDITIONS

Preparation Of The Wood

Moisture content.--The moisture content of any species at the time of gluing should be such that after gluing the assembly will have the moisture content it will average in service (8). This will keep to a minimum the stressing of the joint because of swelling and shrinking of the wood with changes in moisture content.

The average moisture content of wood products that remain indoors (as in homes) throughout the year is about 8 percent in the continental United States (7). The moisture content of these products may vary from 4 to 10 percent in one region, 7 to 12 percent in another, and 10 to 13 percent in another. As the region of ultimate use of a product is seldom known by the manufacturer at the time of fabrication, assembly at a moisture content of 7 or 8 percent is considered most likely to result in least stressing of the glue joints.

Products for exterior use generally are glued at a higher moisture content, because the average moisture content of wood remaining outdoors is usually higher than 7 percent--often around 12 percent.

In gluing lumber or other stock thicker than conventional veneers, the moisture content of the wood before the glue is applied may be about the same as that desired in the finished product. The small amount of water added with the glue, in comparison with the great amount of wood, does not materially change the moisture content of the assembly.

Thin veneers, however, increase greatly in moisture content when an aqueous glue is applied. In a construction having a number of thin veneers, these veneers should be dried to a low moisture content (2 or 3 percent) before being glued.

Lumber to be glued should be free from case-hardening and other internal stresses that may later cause warping, checking, or disruption of the joint. Tests (10) should be made for the presence of these defects, and the stresses

should be relieved before gluing. In addition, beech should be conditioned for a period after kiln-drying so that the moisture content may become more evenly distributed throughout each board.

Surfaces.--The surfaces to be glued should be as smooth and even as possible to obtain joints of highest quality. Proper surfaces on beech lumber are generally achieved only by proper planing or jointing procedures--and with sharp cutterhead knives.

The material should be glued as soon as practicable after being surfaced. This precaution will prevent marked changes in the surfaces due to warping or contamination by grease or other material.

If, for some purpose, it is desired that sawed surfaces be glued, the saw should be kept sharp so that the surfaces will not be burnished or the fibers excessively damaged. Joints made with sawed surfaces may be acceptable for some uses, as in lumber cores or supported-edge joints for interior use, but they will usually not be as strong as joints made with properly planed surfaces because the surface fibers are damaged in sawing.

If beech plywood is to be glued to another member, it is advisable to remove any contamination from the surface of the plywood. Hot-pressed plywood is sometimes glazed or greasy from the hot-pressing operation. The surfaces can be satisfactorily prepared for subsequent gluing by light sanding.

Preparation Of The Glue

Follow the directions of the glue manufacturer in mixing the glue for use. The glue manufacturer formulates a particular glue for certain applications; a deviation from the recommended directions for preparation may cause trouble.

Unless otherwise stated, it is always best practice to weigh all glue ingredients before mixing. In the case of nonresin glues, variations in the proportion of water to glue solids will affect the consistency of the glue and may result in greater tendency towards starved joints, especially with animal glue. Variations in the proportion of catalyst to resin in the resin glues will affect the pot life of

the glue, the rate of strength development, and possibly the water resistance and durability of the joint.

Measuring, mixing, and spreading equipment should be kept clean at all times to prevent old glue from contaminating new batches. For example, if animal glue deteriorated by micro-organisms is left in the equipment, it may infect successive batches of the same glue. Also, if one type of glue is used after a glue of a different type, interference may result if the first glue is not properly cleaned from the equipment. Such is the case if an acid-catalyzed urea-resin glue is used after an alkaline protein or starch glue. Since many modern glues have limited pot lives (that is, the time a glue remains spreadable or usable after mixing), it is important to avoid mixing more glue than can be conveniently used in a given time and to see that equipment is cleaned properly before the glue hardens.

Amount Of Glue Applied

The recommendations of the manufacturer should also be followed in determining the amount of glue to be spread. Since manufacturers may often recommend a range of values, however, the following remarks may be helpful in selecting the proper amount of spread to be used in a specific case.

The amount generally will depend on the type of glue and on the type of construction being glued. In heavy laminated constructions where surfaces may be less carefully prepared, assembly periods may be long, and stresses in services may be great, heavy spreads of glue are required. However, in thin plywood where veneers are well cut and stresses are not expected to be severe, lighter spreads are desired to avoid waste, reduce the amount of moisture added by the glue, and avoid blistering in hot-pressing.

The amount of liquid glue spread (as recommended by the manufacturer) may vary from as low as 30 pounds of urea-resin glue per 1,000 square feet of glue line for hot-pressing plywood of well-cut veneers, to as much as 90 pounds of casein glue per 1,000 square feet of glue line for heavy laminations. Generally, unextended resin glues with high percentages of resin solids will require lower amounts of liquid spread than nonresin glues with lower percentages of solids when used for the same construction. Lighter spreads are usually recommended for hot-pressing plywood than for cold-pressing the same plywood.

Glue is generally applied to only one face of the joint. Where the wood surface is rough or the assembly period is long, spreading glue on both surfaces may be desirable. This double spreading will generally require a higher total amount of glue per square foot of glue line than would single spreading.

Glues of all types are best spread with mechanical roll spreaders. Steel rolls are usually used for alkaline casein and soybean glues, and rubber-covered rolls for resin glues. Rolls are usually corrugated, and the type and size of the corrugations depends on the type of glue and the amounts of spread required. The manufacturers of spreading equipment have given considerable attention to the proper design of these spreader rolls and are in the best position to advise users on the proper type of roll to use. Spreaders are available for spreading both sides or only one side of a veneer or board; and they are also equipped with devices for independently adjusting the amount of glue spread on each side.

For small operations in which the amount of glue used and the gluing areas are small, certain types of glues may be spread with brushes or even spatulas. This does not, however, give close control over the uniformity of the glue spread. Certain resin glues have been applied with spray guns.

It is advisable to check periodically during a gluing operation the amount of glue being applied to the wood. This can be done conveniently by cutting waste veneer to a standard size and weighing it before and after it is run through the spreader. A convenient devise for weighing it is a direct-reading scale that is spring-balanced (requiring no addition of weights) and is graduated in grams. Care should be observed, of course, that both sides of the veneer or boards are receiving the same amount of glue.

Assembly Time

Assembly time is the period between application of glue and application of pressure. In "closed assembly," the surfaces are put in contact immediately after spreading with glue. In "open assembly," the surfaces spread with glue are exposed to the air. In open assembly, glues tend to thicken faster than in closed assembly. For a number of glues, the allowable open-assembly time usually is about one-half of the allowable closed-assembly time.

During the assembly period, the glue in the joint should reach a consistency such that, under the pressure applied, it will be thick enough not to be squeezed excessively out of the joint or pressed into the wood, and yet thin enough to fill the irregularities of the surfaces and form an even film between the surfaces.

Except in the case of hot animal glue, the time at which this consistency is reached cannot be easily determined except by making test joints under various assembly periods. Fortunately, most glues maintain a suitable consistency over a considerably longer period and are less critical in assembly time than animal glues. Animal glues can be formulated for use over a wide range of assembly conditions, but any one formulation can tolerate only a very limited assembly period under a given temperature condition.

The approximate time for application of pressure to an animal-glue joint can be determined in the following manner (12). Spread the glue normally on a piece of beech (or similar species) and note the time required for the glue to thicken enough so it forms short, thick strings when the finger is touched to it and pulled away quickly. (It should not be so thick it resists an imprint readily.) This period is the optimum open-assembly time.

The test results in tables 1 and 2 indicate several conclusions as to the proper assembly periods in gluing beech:

- Starch glue tolerated a closed-assembly time ranging from 5 to 15 minutes. (Previous work has indicated a range of 1 to 60 minutes.)

- Soybean glue gave better resistance to delamination of the joints when a longer closed-assembly time (15 minutes) was used.

- Moisture resistance of casein-glue joints was improved by the longer assembly time (15 minutes) as shown by results of both wet-shear and resistance to delamination tests.

- There was little difference in the results for the 5- and 15-minute assembly times for the room-temperature-setting urea-resin glue.

- In the hot-press, urea-resin glue produced good results at both 5- and 30-minute closed-assembly times.

- The moisture resistance of joints made with hot-press extended urea-resin glue was somewhat greater when a 30-minute closed assembly was used than when a 5-minute assembly was used.

- The results obtained with hot-press phenol-resin glue were equally good at 1-hour and 24-hour assembly times. With certain hot-press phenol resins, blistering may occur with assembly periods as short as 30 minutes.

- Resorcinol-resin glue produced reasonably good results at 5- or 30-minute closed assemblies, but the longer assembly time is generally recommended if high strength is essential.

Note that the above conclusions are based on results of limited tests of only one glue of each type, generally at one assembly temperature (75° F.). The temperatures of the wood and air during assembly will influence the length of the assembly period. With the resin glues, the assembly period will generally be shorter at the higher temperatures. With hot animal glue, high temperatures of wood and air will tend to slow gelation, and thus will increase the assembly period. It is therefore important to follow the assembly conditions recommended by the glue manufacturer.

Temperature Of Glue And Wood

Except for hot animal glue, the temperature of the glue mixture at the time of spreading is relatively unimportant within a range of 60° to 90° F., except as this temperature may limit the pot life of the glue. In fact, it is sometimes desirable to cool mixtures of some resin glues below shop temperatures in the summer months in order to prolong the life of the mixed glue. Animal glues should be kept at 140° to 150° F. (12). Higher temperatures tend to degrade animal glues excessively, and lower temperatures tend to foster the growth of micro-organisms that deteriorate the glue.

The proper setting or curing of the glue is related to the temperature of the wood and of the room or shop during the assembly and pressure periods. The room-temperature-setting synthetic glues (urea and resorcinol resins) do not cure properly to full moisture resistance (6)

unless the temperature of the glue line is at least 70° F. The strength of joints made with resorcinol-resin glue was somewhat higher when the curing temperature was 90° F. than when it was 75° F. (table 2). Experience has shown that still higher temperatures (above 90° F.) are necessary for curing resorcinol-resin glue to produce joints of maximum durability in constructions made with heavy species like beech for severe service. A comparison of the data in table 1 for an unextended room-temperature-setting urea resin and an unextended hot-press urea resin also indicates superior joint-strength and wood-failure values for the hot-pressed glue. Some urea-resin glues, however, are capable of producing joints at 80° F. (in yellow birch plywood) with higher shear strength than shown by the room-temperature-setting glue used in this work (3).

The nonresin glues, including animal glues, will usually produce satisfactory joints even if the temperature of the wood is below 70° F. (as low as 40° F.), provided the other gluing conditions, particularly the assembly time, are properly controlled. With animal glue, however, the possibility of producing poor joints due to chilling becomes much greater as the temperature of the wood is lowered below 70° F. and generally in such cases the most practical solution is to warm the wood to at least 70° F. The animal, starch, and casein glues will develop strength somewhat faster at temperatures slightly raised above room temperatures, apparently because of faster removal of moisture from the glue lines. These heating techniques, however, are used less frequently for these glues than for the resin glues.

Hot-pressing temperatures recommended by glue manufacturers are generally 240° to 260° F. for urea-resin, fortified urea-resin, and melamine glues, and 300° to 320° F. for phenol-resin glues. The results included in table 1 show that a curing temperature of 310° F. was suitable for the phenol-resin glue used.

As in other gluing conditions, the recommendations of the glue manufacturer on curing conditions should be followed for any particular glue.

Pressure And Pressure Period

It is important to insure both adequate and uniform distribution of gluing pressure. A pressure of 150 to 250 pounds a square inch generally should be applied.

If the mating surfaces can be brought easily in contact, as with thin, well-cut veneers, a pressure toward the lower part of the range may be used. But with thicker members the assembly should be under a pressure of 200 to 250 pounds per square inch.

Many pressure devices, such as screw clamps, are not equipped with pressure gages, but approximate pressures may be computed (11). With such screw clamps, it is particularly important to provide proper spacing of clamps to insure uniform distribution of pressure.

The pressure period, or length of time the joint should be under pressure, varies with the temperature of the assembly, the type of glue, and the construction of the assembly. Edge-glued joints made with animal or casein glues may require only about 1 hour under pressure to set to a strength that will allow release of pressure. Similar joints made with starch glues may require somewhat longer periods. Such assemblies, however, must not be roughly handled or machined upon removal of pressure, but should be stacked carefully to allow the glue to set completely.

The resin glues, when cured at room temperature of 70° F., generally develop strength somewhat more slowly than do the nonresin glues. For this reason, if faster cure and shorter pressure periods are desired, heat is usually applied to joints made with these resin glues to hasten the chemical reactions of curing. With edge-glued joints, this may be done in a variety of ways, such as (1) placing the clamped assembly in a heated chamber (at 110° to 140° F.) for about 1 hour; (2) passing the joints between heated platens (at 300° F.) for about 2 minutes; or (3) heating the glue line in a high-frequency dielectric field for less than 1 minute.

Plywood, laminated members, or other highly stressed assemblies made with room-temperature-setting glues should be held under pressure for longer periods, usually from 6 hours to overnight.

A particular type of soybean glue has been formulated to set in a shorter time. The results of tests of plywood joints made with this soybean glue, under pressure for only 30 minutes, are given in table 1. The other conditions of gluing, particularly the consistency of the glue and the assembly period, must be carefully controlled in using such

a short pressure period. It is also important to handle the assemblies carefully when removing them from the press and to stack them carefully for several hours to complete the setting of the glue before machining. Plywood made in a hot-press should be under pressure for the period recommended by the glue manufacturer. This period varies with the particular glue, the temperature of the platens, the thermal conductivity of the cauls, and the thickness and number of plies.

Conditioning The Assembly After Gluing

In most gluing processes, moisture is added to the assembly by the glue. Most of this added moisture may be removed if the joints are cured by hot-pressing, but the moisture added by room-temperature-setting glues generally must be removed from the assembly or distributed through the assembly during a conditioning period after gluing. The purpose of conditioning after gluing is to reduce the possibility of change in shape and dimension during further processing and use. Proper conditioning may also prevent staining of plywood faces by highly alkaline glues such as casein and starch.

In edge-glued joints, the moisture content of the entire assembly may be increased by less than 1 percent by the addition of the glue. Immediately after the gluing operation, however, the wood adjacent to the glue joint contains a relatively large amount of moisture. This moisture must be allowed to distribute itself through the rest of the wood before the assembly is machined; otherwise sunken joints will result. To avoid sunken joints completely, edge-glued lumber 1 inch thick should be stickered and dried for 7 days at 70° to 80° F., 4 days at 120° F., or 24 hours at 160° F.

Plywood glued at room temperature is best conditioned on stickers in a heated room. The thinner panels ($\frac{1}{4}$ inch or less) may be dried satisfactorily in 8 to 16 hours, and lumber-core panels in 24 hours at 100 F. If the faces of the plywood are thin (1/16 inch or less) and casein, soybean, or starch glue is used, it is essential to start the drying operation as soon as possible to prevent staining of the faces by the alkali, which diffuses to the surface of the panels when the moisture content of the veneer is high.

The moisture content of hot-pressed plywood, particularly when made with phenol-resin glues that require curing

at 300° F. or higher, may be too low after the plywood is taken from the press. Moisture may be added by applying a fine spray of water to the faces or by passing the panels through wet rollers. The moistened panels are then stacked solidly to allow the moisture to distribute throughout the panels. This reduces distortion of the panels to a minimum.

INSPECTION & CONTROL TO INSURE SUITABLE GLUING CONDITIONS

It is important to recognize that the quality of any glue joint is determined both by the glue selected and the way in which the glue is used. There are certain methods that may be used to check the quality of different batches of glue.

These methods are described in various specifications and generally require joint tests to be made with special test machines that may not be available in many shops (1, 2). Simple tests, however, can be made on glue samples by preparing test joints of two blocks of wood (beech in this case) under the proper gluing conditions. These joints can then be tested by forcefully separating the laminations at the glue line with a suitable tool. High percentages of failure in the wood in such joints are indications of satisfactory performance of the glue.

Another useful check test that can be made on different batches or shipments of some types of glue is a pot-life determination. For this test, a small sample (about one-half pound) is prepared carefully, and the consistency for spreading is noted by hand stirring and observation over a period of time at a uniform room temperature. Different types of glue gel or harden at different rates, but different batches of the same glue should behave similarly.

It is likewise important to insure that good gluing conditions will be used in the actual gluing process. Since it is not possible to test joints in production without destroying the joints, the various phases of the gluing process, including performance of the equipment, should be continually checked. Some of the items that need to be controlled are:

Condition of saws and planer knives.--The saws and planer knives should always be kept sharp, and their bear-

ings and arbors in good mechanical condition. Frequent inspection of gluing surfaces should be made to find whether these surfaces are clean, smooth, and even.

Moisture content of the wood.--The moisture content of beech going into production may be measured with a moisture meter or by using the oven-drying method to determine moisture content (5). The moisture content of the glued product after conditioning should also be determined. Since the moisture content of different boards dried at the same time will vary considerably, it is important to check the moisture content of several representative boards rather than a single board.

Condition of pressure devices.--Clamps, I-beams, turnbuckles, platens, and cauls should be kept clean and free of deformation to insure a minimum variation in pressure. Pressure indicators should be calibrated periodically for accuracy. Press loads should be uniformly stacked in clamps to insure proper distribution of pressure. Hydraulic pressure systems should be checked to insure continued satisfactory operation. In some applications, such as when hot animal glue is used, or when resin glues are hot-pressed in multiple-opening presses, application of gluing pressures should be sufficiently rapid to avoid excessive assembly periods that might cause premature curing of the glue.

Temperatures.--Shop temperatures should be checked at frequent intervals to avoid unexpected changes in temperature. This is probably most important in using hot animal glue, but minimum temperatures should also be maintained for using the resin glues, as previously discussed. In heating joints for curing, particularly with the resin glues, it should be noted that wood is a poor conductor of heat and that in thick assemblies, a particular glue line may not reach the temperature of the curing chamber or heated platens for some time after pressure and heat are applied. Since most resin-glue manufacturers specify that certain minimum glue-line temperatures be maintained in curing, additional time must be allowed for heating the wood. The actual glue-line temperatures can be determined directly by means of thermocouples and a temperature-reading potentiometer. In steam-heated platens, it is important to check valves and traps to insure uniform heating throughout the platens.

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The information gathered in this widespread cooperative project should be of great use to the wood-using industries of the regions where the wood of American beech is available.

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